Challenges and potential improvements of systems analyses for sector coupling: a discussion along the dimensions of socio-technical problems

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A discussion along the dimensions of socio-technical problems

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This paper discusses the challenges of systems analysis for policy advice in the context of sector coupling along the three dimensions of socio-technical problems: control, change, and action. Research shows that the challenges of systems analyses increase significantly when considering sector coupling, both with respect to the choice of areas of investigation and with respect to the basic methods and practices of systems analysis for policy advice. In particular, social aspects and practical expertise need to be considered, results of different studies should ideally be combinable for reflexive meta-analyses, and analyses should focus on key messages.

Herausforderungen und Möglichkeiten zur Verbesserung von Systemanalysen zur Sektorkopplung
Eine Diskussion entlang der Dimensionen soziotechnischer Probleme

In diesem Beitrag werden Herausforderungen der Systemanalyse für die Politikberatung im Bereich der Sektorkopplung entlang der drei Dimensionen soziotechnischer Probleme diskutiert: Kontrolle, Veränderungsprozesse und Handlungen. Es zeigt sich, dass Herausforderungen von Systemanalysen unter Berücksichtigung der Sektorkopplung deutlich steigen, sowohl hinsichtlich der Wahl der Untersuchungsbereiche als auch hinsichtlich der grundlegenden Methoden und Praktiken der Systemanalyse zur Politikberatung. Insbesondere gesellschaftliche Aspekte und praktische Expertise müssen berücksichtigt werden, Ergebnisse verschiedener Studien sollten idealerweise für reflexive Metaanalysen kombinierbar sein und die Analysen sollten sich auf die wichtigsten Aussagen konzentrieren.

Keywords: *systems analysis, challenges, sector coupling, robustness, energy supply*

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Introduction

Current plans for modifying energy systems in order to meet greenhouse gas reduction targets particularly include using much more fluctuating renewable energy sources than nowadays. Thus, the need for system flexibility increases significantly (Ausfelder et al. 2017). Ensuring secure and safe energy supply in spite of such a system transformation process requires to intelligently combine electricity and heat supply as well as applications in sectors with large energy consumption. This means to come much closer in touch with societal habits and needs than in current energy systems. As result "socio-technical problems" may arise from energy transition processes. Büscher (2018) made up three facets which are to be analyzed in this context: the problems of control, change and action. In this contribution these dimensions are taken for structuring the discussion of challenges connected with energy system analyses as identified by Droste-Franke et al. (2015), sketching additionally first experiences from practical attempts to improve systems analyses with the focus on sector coupling.

General challenges of systems analyses

Droste-Franke et al. (2015) analyses challenges of systems analyses for policy advice following the approach of rational technology assessment, using ethical reflection to propose rational options (Decker and Grunwald 2001; Grunwald 1999; Grunwald and Saupe 1999; Decker 2004). Accordingly, a scientific expert group was set up, extended by further experts in two workshops. Recommendations for the design of systems analysis were elaborated in intensive interdisciplinary reflections on framework conditions and on the virtue of systems analyses for policy advice. Lines of rational arguments were made visible and as far as possible preconditions and causal links as well as descriptive and normative elements were dissected to derive recommendations.

Droste-Franke et al. (2015) focus on general challenges of systems analyses for policy advice. Basic results from their argumentation taken up here are

- the need for dynamic stability and social robustness in solutions and analyses,
- recommendations on how to proceed in typical systems analyses to reach such a robustness, and
- a specific culturally based systems view supporting to distinguish systems and their environment as well as to evaluate the explanatory power of analyses.

In their argumentation Droste-Franke et al. (2015) start with general aims of an energy supply system. Following them, basic requirements are that

- the system should be designed in a way that the essential function of providing usable energy to the consumer can be guaranteed and
- unintended "negative side effects should not outweigh the intended effects" (ibid, p. 5).

Having in mind the increasing amount of fluctuating and non-disposable power in the system, besides safety also security requires particular attention when designing future energy systems.

The proposed concept of dynamic stability is basically referring to two requirements for future energy supply: robustness and opportuneness (Ben-Haim 2006; Carrier 2010). Robustness means that solutions for energy supply ensure "staying within an admissible corridor where one is safe against adverse effects" (Droste-Franke et al. 2015, p. 9). Opportuneness means to ensure that "we are able to take advantage of opportunities that open up unexpectedly" (ibid, p. 9). The market is not able to stimulate such solutions by itself. Instead a "comprehensive scheme, which is best developed by drawing on foresight and epistemic penetration, is required … This is why science-based policy advice can prove helpful in exploring the dynamically stable pathway toward a robust energy supply system." (ibid, p. 12). Social robustness means "that at an expert analysis or recommendation is acceptable within a wide spectrum of diverse interests and value commitments" (ibid, p. 13). It aims to achieve social inclusion in order to elaborate acceptable solutions.

According to the types of solutions needed, expert advice should be a reliable guide to secure energy supply even under unforeseen circumstances. For this purpose, it is important to analyses a full range of options. The focus should be laid on their striking features which mean difference for decisions on human action. Furthermore, the technologies employed "should operate in conformity with the interests and values professed within the society concerned" (ibid, p. 39). A typical process could be designed in a way that in a first step an analysis of options is carried out from which in a second step, preferred options can be selected by taking the interests and valuations of the concerned society into account. This should ideally be done by comprising a wide range of interests. Final decisions on actions to take have to be made by legitimated political bodies.

The systems view taken by Droste-Franke et al. (2015), based on Janich (2001), was specifically designed to support the design of new studies and the evaluation of existing studies. Its fundamental approach is to distinguish systems from their environment in two orthogonal dimensions: the operational and the intentional dimension ("systems-web approach") (Droste-Franke et al. 2015; Droste-Franke 2015). Following this system perception, in the operational dimension a system develops automatically from the formal operation which corresponds to the disciplinary perspective taken to describe certain circumstances: characteristics of entities which can be influenced by the operation are part of the system, all other characteristics of entities belong to the environment (operationally closed system). In the intentional dimension, the intention of the analysis carried out allows to clearly separate the elements of the system from its environment: all characteristics of entities which are seen as relevant for the purpose of analysis are elements of the system, all others are not (intentionally closed system). Combining both dimensions results in the view that a system consists of all characteristics of entities which are affected by the chosen formal operation which are relevant for the purpose of analysis. For instance, the "energy supply system" unfolds as a bundle of characteristics of elements which, according to their chosen formal descriptions, have influence on conditions of supply and consumption of usable energy. For instance, from the physical perspective, energy fluxes to entities which cannot be used for energy supply represent energy losses from the system and are thus released to the system's environment. Relevant operations include all scientific and practically based descriptions or disciplinary perspectives (social, technical, economical, psychological etc.) which are relevant for the design of future energy supply systems.

In the following, more detailed insights to challenges of systems analyses for policy advice and potential solutions are discussed along the approach of socio-technical problems.

Expert advice should be a reliable guide to secure energy supply even under unforeseen circumstances.

Challenges of systems analyses along three dimensions of socio-technical problems

Three dimensions of socio-technical problems

Büscher (2018) defines three "dimensions" or "facets" of socio-technical problems, control, change, and action, which are used to get a deeper insight into problems arising with the energy transition. These are taken here as starting point for structuring the more detailed discussion of particular challenges for systems analyses in the context of sector coupling. Büscher (2018) makes up three facets, as briefly sketched in the following:

- The problem of control: It includes structural characteristics of systems, particularly, the aspect of knowing about "relations of heterogeneous elements", in order to enable operating energy supply according to societal needs. Technical issues and social issues are distinguished here as well as internal (system) and external (environment) issues.
- The problem of change: It is defined by Büscher (2018) as a trade-off between enabling change and ensuring security by redundancy. In this facet institutional aspects are particularly addressed.
- The problem of action: this facet concentrates on problems of operation and decision making which develop particularly when technical processes are substituted by social processes with different time scales and higher simultaneity. According to Büscher (2018) increasing uncertainty can be absorbed by social arrangements or technical devices providing trust and confidence.

A discussion of these three facets of socio-technical problems can also be found in the introduction (pp. 11–16) and in Büscher et al. of this TATuP special topic (pp. 17–23).

Considering the problem of control

For the problem of control, various technical and social aspects need to be taken into account: the complete chain of interacting elements applied for energy supply (energy supply system), impacts of circumstances in the environment on this system, and vice versa, and options of inputs to the system needed for reaching a certain expected output. As the chain consists of technical as well as social elements, a necessary synchronization of all processes is very complex, especially if circumstances change.

Control is the domain for which particularly system knowledge is needed. In order to capture all problems of this dimension, first the knowledge about the system and all processes to establish and operate a system need to be known. As introduced above we follow here the system perception of Droste-Franke et al. (2015), distinguishing an operational and an intentional dimension. In order to analyses an energy system and its linkages to other sectors with respect to its future design, societal and natural framework conditions need to be taken into account. Thus, in addition to formal descriptions of physical and technical aspects perspectives of social and psychological science, but also of other natural and especially geo-sciences etc. are required. Additionally, scientific insights need to be supplemented by practical aspects in the areas of regulations, responsibilities, knowledge and societal and individual beliefs etc. In this way a web of descriptions develops which becomes denser with each perspective complemented.

The necessity of considering the individual disciplinary perspectives comes with the necessity of analyzing the inter-connections via the involved entities in an interdisciplinary manner. Exchange between the systems takes place via the entities. Processes in one system may lead to changes in entity characteristics relevant for another system.

Scientific means are designed to provide general descriptions which here need to bear in a certain fixed context of application. In order to be able to provide epistemic robustness, additionally the following practical expertise is needed:

- technical expertise: knowing how to follow a "fixed canon of rules" (ibid, p. 36),
- professional expertise: proceeding "on the basis of exemplars or precedents" (ibid, p. 36),
- local, experience-based expertise: "advanced knowledge in virtue of … [the experts] familiarity with the relevant domain" (ibid, p. 41).

In most cases, these expertises can also be sorted into disciplinary description systems. An inclusion of such additional expertises can be realized by establishing respective co-design processes, including all relevant experts and stakeholders into the process. Experience has been gained in various projects, e. g. in the "FONA Research for Sustainable Development" program, project "Helmholtz Alliance ENERGY-TRANS" and Kopernikus project "ENavi". One of the projects in "FONA" is the EnAHRgie[1]. The innovation group as the core working group was assembled following the recommendations of Droste-Franke et al. (2015). It consisted of local representatives from banks, companies, handicraft, administration, civil society organizations, energy suppliers and scientists from different disciplines: engineering science, political science, legal science, technology assessment and economics. For instance, due to the discussion process with the practitioners, the scientific analysis was significantly changed by concentrating on carrying out a multi-criterial scenario development instead of modelling the technical distribution grid which was originally planned.

With sector coupling, regulations become much more complex than without, because devices formerly used only for specific purposes like cars and heating systems need to be con-

1 EnAHRgie: Nachhaltige Gestaltung der Landnutzung und Energieversorgung auf kommunaler Ebene. Umsetzung für die Modellregion Kreis Ahrweiler, Förderung: BMBF, FONA, Innovationsgruppen „Nachhaltiges Landmanagement", FKZ: 033L110

nected to the energy system in order to provide more flexibility. Systems analyses of the more complex technical system become much more ambitious in many respects: options competing for the same system tasks are of different nature, are situated in different locations and on different levels of the energy supply system, e. g. the provision of balancing energy by large power plants competes with flexibly charging batteries in electric cars at home. Figure 1 shows directly competing balancing technologies. All those options need to be considered for adequate systems analyses, considering also many more societal aspects and restrictions. Furthermore, researchers of different disciplinary fields like transport and energy system research who did not cooperate before, need to work hand in hand to derive meaningful analyses.

Droste-Franke et al. (2015) show already that many energy system studies differ even in the technologies considered, with the effect that the results are not comparable. Furthermore, most of the analyses concentrate on pure cost-effective solutions. Even studies dealing with sector coupling in an interdisciplinary setting like Ausfelder et al. (2017) are not able to provide a full picture. Arguing mainly from a techno-economic perspective, they miss aspects such as more concrete analysis of environmental and resource aspects, local added value, occupational effects etc. The example shows how hard it is to take all relevant perspectives in one study. Establishing studies with various foci, temporal and spatial scale which are combinable for reflexive meta-studies could be a solution here.

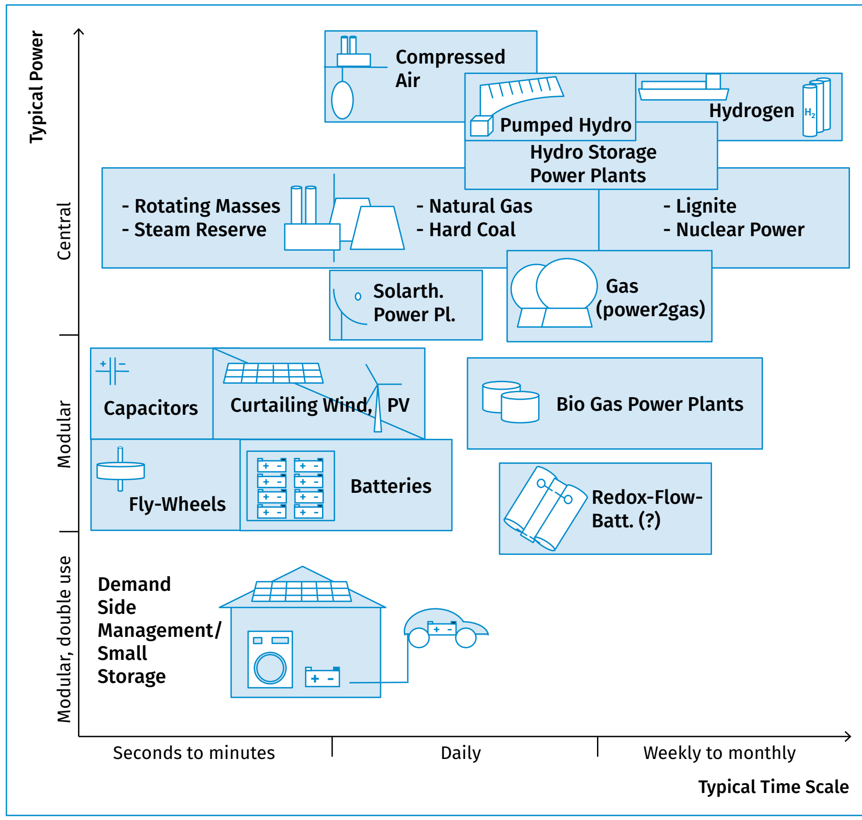

Fig. 1: Competing technologies to provide flexibility in the energy supply system (horizontally: same power range; vertically: same temporal scale). *Source: Droste-Franke et al. 2015, p. 106*

Considering the problem of change

As shown above, Droste-Franke et al. (2015) address the continuous problem of balancing change and security. They focus on designing an energy supply system which can provide a secure operation under a variety of framework conditions which may potentially change over time due to events external to the system. Stability of the system operation in spite of changing circumstances is emphasized as very important. Following their argumentation, the role of scientific experts for policy support is to identify a number of good solutions which can ensure stable operation under a variety of circumstances and that these can be changed as soon as superior solutions are available. This includes analyzing options for the change process which Büscher (2018) concentrates on. In designing this process, they see again the need to consider all expertise which is required in order to assure that the solution fits to the purpose.

The approach of the project EnAHRgie, already discussed for the problem of control, shows how an expert group consisting of scientific and practical experts can be compiled and consulted to develop an energy concept following the recommendations of Droste-Franke et al. (2015). By doing this, the initiated process follows a certain workflow carried out with scientific and practical experts. First, questions are collectively derived. Then appropriate systems analyses are designed and carried out. In a next step, the results are reflected and reviewed with respect to them providing answers to the posed questions. Finally, analyses are finetuned and results are updated in at least one iterative slope. The realization of the approach in the project EnAHRgie represents a variation of the workflow initially proposed by Schilperoord and Ahrweiler (2014) for the analysis of innovation networks (Droste-Franke 2018).

Carrying out meaningful systems analyses in the realm of change is a very specific endeavor, because change is particularly steeped in a large number of incremental and radical innovation processes on multiple scales, changing products, processes and structures (Ahrweiler 2010; Fagerberg et al. 2006; Schumpeter 1912). Such innovation processes take place on various levels and are by far too complex to capture them by system correlations (Kline and Rosenberg 1986). Particularly, unforeseen processes of creative destruction, as introduced by

Schumpeter (1993), represent non-linear developments in a way that completely new elements – we could not think about beforehand – enter the scene. These can impossibly be simulated by dynamic system modelling. Nonetheless, other models like agent-based models can be applied for systems analyses in such contexts by simulating the acting of agents on a micro-level and observing what happens in the innovation system on meso-level (Gilbert 2008).

Some potentials and challenges of such analyses can be drawn from experiences with modelling innovation processes in the InnoSEn-project (the case of lithium batteries as a core technology for coupling energy and transport).[2] In order to assure a model design and respective analyses which fit to the purpose, the above described workflow was initiated for the model set-up. Experts from respective national associations, innovation research, acting companies and research funding agencies were involved by three workshops. First, questions were elaborated taking into account the heuristics of technological innovation systems, then the model was built in a way to be able to answer these questions, intermediate results were discussed and the analyses were updated to achieve refined answers (Droste-Franke and Fohr 2017; Globisch et al. 2019).

Researchers need to work hand in hand to derive meaningful analyses.

The exercise of adapting the basic SKIN (Simulating Knowledge Dynamics in Innovation Networks) model developed by Gilbert et al. (2010) to model the technological innovation system exposed various challenges. From first experiences of the simulation it can be stated that micro processes can be described quite well. Simulations show reasonable results in various details of the model and modelled effects on the meso level fit well to empirical findings for such innovation processes. In addition, types of actors can be calibrated well by existing data in order to realize reasonable proportions in numbers. For modelling future processes, it has to be borne in mind that currently existing structures are subject to continuous change. Due to lack of knowledge about causal correlations in the complex realm of innovation processes, based on statistical analyses, random actors with typical characteristics are modelled instead of concrete individual actors. Furthermore, the implementation of the core evolutionary random mechanism in knowledge generation cannot be calibrated in detail, let alone validating calculations with respect to empirical data. One main reason is missing detail in data from comparable past developments including prevailing framework conditions. Furthermore, influencing framework conditions and actor structures of the technological innovation system are continuously changing and their emergence in the future is unknown. Thus, depending on complexity and future uncertainties of relevant framework conditions, validation by comparing past situations with potential future ones is hardly possible, or not possible at all. Nonetheless, the strong descriptiveness of micro processes and the plausible patterns in results make it a well-founded tool to carry out comparative explorative analyses of measures to foster innovation dynamics. In experiments hypotheses of impacts can be tested by comparing results for different options and analyzing their emergence. As outcome, the rational foundation for the application of such measures can be further enhanced beyond merely empirically analyzing past situations. Such a tool is particularly applicable to analyses measures to increase innovation dynamics for transitions processes.

Tackling the problem of change for sector coupling would mean that processes need to be developed in a way that institutions change smoothly according to technological change so that secure energy supply is ensured at each point in time. This means to ideally coordinate and consider formal and informal institutions in many places of societal action and of various temporal scopes in a way which was not needed before. An example is coordinated adequate change of curricula in education and training of the handicraft to enable and to convince installers to sell respective technical devices and to develop fitting maintenance services. This is one prerequisite for introducing harmonized combinations of devices needed for sector coupling such as (bi-directional) loading of electric vehicles, heat pumps, CHP systems, fuel cells, heat storage, (small) electrolyzers, photovoltaics, and batteries. Systems analyses combining social and technological simulations can support decision making with providing theoretical insight in socio-technical circumstances for which experience is not yet available.

Considering the problem of action

In terms of risk and uncertainty, Droste-Franke et al. (2015) discuss various kinds of hazards distinguishing two basic dimensions. The first dimension is if "all influential factors can be reasonably expected to be known" (ibid, p. 46). The second dimension is if probability estimates are available. Following the categories of risks (all influential factors and probability estimates are known), uncertainty (known outcomes, but no observable probability) and deep uncertainty or ignorance (unknown factors may exist and have strong impact), in the case of energy transition and sector coupling we have the situation of structural change in which observed probabilities may no longer hold. This holds more specifically if social processes replace technical in-

2 Netzwerkanalyse und Simulation von Innovationsdynamiken neuer Schlüsseltechnologien im Energiebereich (InnoSEn), BMWi, FKZ: 03ET4032

terconnections as discussed by Büscher (2018). In such cases experience-based knowledge may be misleading as it is based upon experience under previous conditions and without the new elements in place. Systemic, theoretical knowledge-based analyses will usually have better chance to succeed in these contexts. Following Droste-Franke et al. (2015) scientific policy advice addressing uncertainty of this kind should consider three components to be able to provide valuable policy advice in complex matters:

- bringing in local knowledge and lay experience of certain important aspects which may still be important to design robust solutions;
- strengthening the knowledge base by analyzing interdependencies and causal relations further;
- providing epistemically robust advice by reducing the statements to robust results providing main messages which remain stable under all possible interpretations in the area of high uncertainty.

The challenge for systems analyses in this case is to analyses options to design processes which can be similarly reliable as technological processes despite unknown behavior of individuals. Also, in this case social simulation, e. g. via agent-based modelling, may help. Starting with a categorization of potential behavior according to different types of individuals including assumptions for its potential change in the future, e. g. for decision situations, social processes can be analyzed and measures can be designed in order to increase security of supply. This would strengthen the knowledge. In case that calibration and validation again turn out to be difficult, the analysis of striking interlinkages could at least provide better insights into potential effects. This holds particularly if stable main messages can be identified. Another challenge lies in the communication of the results. An adequate interactive visualization of the complex interlinkages implemented in the model and the main messages in the results as well as the respective uncertainties of the modelling process could establish confidence in the system on the side of the decision maker.

For the case of sector coupling, those researchers interested in providing rational orientation for decision-making have to consider many more aspects of various disciplines, on different levels of technical systems and society than before. The current difficulties with providing and communicating energy systems analyses show that new ways need to be found to provide knowledge about striking consequences of actions to decision makers, providing main messages including involved uncertainties. Additionally, decision makers need to be made familiar with making decisions based on such results (Droste-Franke et al. 2015).

For the definition of processes to replace technological parts of the system, e. g. implemented and tested in simulations and model experiments, incorporating practical knowledge is specifically important. Knowledge of action, technical knowledge and maybe professional knowledge, does not only comprise knowledge about the consequences of action, but also of knowledge about how to act. In order to define a scheme for action as basis for such processes in a way that it is successful and the intended impacts are accomplished (Janich 2011), even small details may be important. Particularly options to develop and transfer "tacit knowledge" – knowledge which "cannot be expressed outside the action of the person who has it" (Foray 2007) – need to be considered in respective modelling exercises and when establishing effective learning or training processes[3].

Increasing flexibility of the energy system by sector coupling means establishing and coordinating many more of these processes than before, both in various sectors and on multiple levels. The need for practical knowledge for defining and establishing societal processes further emphasizes the increasing need for participatory co-design analyses as already discussed above.

Conclusions

Discussing challenges of energy systems analyses for policy support along the three facets of socio-technical problems in combination with first experiences of applying such approaches, reveals that the need for sector coupling significantly increases challenges of energy supply and systems analyses. It fosters extending systems analyses by explicitly considering societal aspects in detail and combining them to provide insight into decisive consequences of decisions. Furthermore, practical knowledge becomes more important and needs to be taken adequately into account. Additionally, analyses of various detail and on different levels should ideally be comparable or even combinable to enable reflexive meta-analyses of main correlations.

The experiences discussed show options for tackling the problems by systems analyses. They suggest that successful approaches should include more concretely:

Incorporating practical and tacit knowledge is specifically important for simulations and model experiments.

3 Although tacit knowledge cannot be expressed, specific situations can be established in which intensive learning, e. g. via iterative imitation and correction, potentially combined with trial and error cycles, lead to a certain transfer of tacit knowledge. Modelling can consider if such situations prevail and transfer of tacit knowledge in the described way is likely in the modelled circumstances.

- enabling close involvement or in depth and detailed consideration of expertise from science and practice in designing and carrying out meaningful systems analyses,
- modelling more of the relevant (formal) systems of various scientific disciplines and practical aspects on the basis of fundamental characteristics and behavior of entities which will prospectively remain unchanged over time,
- communicating and providing study results transparently so that they can be taken up by others for reflexive meta-analyses in concrete decision situations and maybe can even be transferred to related areas, and
- presenting results of systems analyses in a way that the public and decision makers can make themselves familiar with uncertainties and sensitivities in order to be able to assess the meaning of the results for their individual area of interest.

Thus, not only the areas of analyses need to change, but also the kind of analyses carried out and the presentation of the results. These challenges run counter to current practice and basic methodologies of systems analyses and ask for creative solutions and innovative kinds of system analyses.

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